Proposal for (p,p) and (p,N) Collision Experiments at Batavia

by use of Nuclear Emulsions and Electronic Detectors

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SUMMARY

In this project we propose to measure

(1) the elastic differential cross-sections of 100-500 GeV protons in (p,p) collisions by use of nuclear emulsions, and

(2) the energy spectrum and $\frac{d\sigma}{dEd\Omega}$ of the light fragments ${}_1H^2$, ${}_1H^3$, ${}_2He^3$, ${}_2He^4$ in (p,N) collisions at the same energy range using the electronic E-ΔE detectors.

INTRODUCTION

In the elastic (p,p) scattering at high incident laboratory energy E_p and low momentum transfer t, the differential cross-section can be approximately given by

$$\frac{d\sigma}{dt} = \left(\frac{d\sigma}{dt}\right)_{t=0} e^{bt/2}$$

where $e^{bt/2}$ = nucleon form factor and b = slope parameter. This approximation was deduced by applying the Regge Pole Theory to the relativistic case[1,2]. The value of b has been measured in some 20 different experiments[3]. The pre-1971 data[2,4,5,6,7], which were obtained at E_p up to 70 GeV, agree well with the prediction based on this approximation. It was found to be a linear function of s (total c.m. energy squared) or simply E_p (because $s \simeq 2\, m_p E_p$ in the (p,p) relativistic scatterings). Specifically speaking, the measured b value increased from 7.5 to 11$(GeV/c)^{-2}$ when E_p changed from 2 to 70 GeV. However, the 1971 data obtained from the (p,p) scattering at the c.m. energies (15.34 + 15.34) GeV and (22.47 + 22.47) GeV at the CERN ISR[8] yield the value of b which was significantly less than expected from the extrapolation using the pre-1971 findings. This fact indicated that the Regge pole approximation may not be valid at very high energies. Since no data are available yet at the E_p range from 70 GeV to 500 GeV, further experiments are needed in order to check the ISR data. With this in mind and in view of the forthcoming Batavia proton beams with an energy up to 500 GeV, we propose to measure the value of b at this energy gap as function of s and t in order to see whether the behavior of b within the 100-500 GeV range agrees with the recent ISR data. Based on our experiences obtained from a similar experiment done at CERN using the 27 GeV proton beam, we intend to use emulsions as the detectors in order to achieve the precision energy and angular measurement because the emulsions provide an excellent spatial resolution of 0.2μ. Figure 1 displays part of the data from the (p,p) experiment at 27 GeV.

The second part of this proposal will study the light fragments H^2, H^3, He^3, He^4 emitted from the nuclear disintegration in (p,N) collisions at 100-500 GeV. A number of experiments along this line with protons[9-12] (from 3 to 20 GeV) and with pions[13] (60 GeV) revealed several important features. Among the features are (1) emission of He nuclei with much higher energy than the Coulomb repulsion between the two proton in the nucleus (e.g. it reached 2500 MeV at E_p = 20 GeV)[11], (2) the production cross-section and the energy and angular distributions of the fragments apparently depend neither on the incident energy nor on the nature of the incident particle, and (3) the production cross-section for energetic fragments depends on the atomic number of the target nucleus. Attempts have been made to attribute these phenomena to Hagedorn's Statistical (or called Thermodynamical) Model[14], and the Nuclear Cascade Theory[15]. However, none of the proposed mechanisms can completely explain these observations. Since the nuclear disintegration with doubly-charged particles emitted is characterized by extremely small cross-sections ($\sim$0.2 mb for helium energy > 1000 MeV at E_p = 20 GeV), more experimental data with good statistics are needed in obtaining further information on the (p,N) collisions and possibly creating a new theoretical model for explanation.

Under these considerations, we propose to use the Batavia 200-500 GeV proton beams to induce the nuclear disintegration in C, Al, Fe and Au and measure the differential cross-section $\frac{d^2N}{dEd\Omega}$ and the energy spectrum of H^2, H^3, He^3, and He^4. Based on our experiences obtained from Experiment SC33[12] at CERN, we plan to use the electronic E-ΔE detectors for charge identification and energy measurement. As a reference from Experiment SC33, Figures 2, 3(a) and 3(b) display part of the data on the energy spectrum and $\frac{d^2N}{dEd\Omega}$ for the fragments.

It is appropriate to point out that the first and second parts of this proposal can be performed simultaneously, which will save the beam time considerably.

THE EXPERIMENT PROPOSED

As stated in the preceding section, we propose to use nuclear emulsions to measure $\frac{d\sigma}{dt}$ at low momentum transfer t in the elastic (p,p) scattering and to employ electronic detectors to measure $\frac{d^2N}{dEd\Omega}$ and energy spectrum of the light fragments in the (p,N) nuclear disintegrations. The requirement and specifications of the beams, exposures, targets, detectors, etc. are summarized below:

(1) Beam and Exposure Time

For the convenience of scanning and measurement it will be desirable to record about 10^3 recoil-protons/cm^2 in the emulsions. The exposure time will be determined on the basis of this consideration and the beam intensity. Since we intend to use the beams at 100, 200, 300, 400, 500 GeV, we will need a total of about 30 exposures which includes the test runs. Roughly speaking, each exposure will take 3 to 4 hours.

(2) Targets

Thin sheets (about 3μ thick) of $(CH_2)_n$ and pure carbon will be used as the targets in connection with the nuclear emulsion stacks as the detectors. These targets should yield data on the (p,p) elastic cross-section based on the CH_2-C difference method[4,5].

For the study of the (p,N) inelastic collisions, we will use C, Al, Fe and Au as the targets (about 15 to 50 mg/cm^2 thick). These are to be used along with the electronic detectors for the measurement of light fragments energy spectrum and the corresponding differential cross-section $\frac{d^2N}{dEd\Omega}$.

(3) Detector System

Figure 4 illustrates the sketch of the system. It consists of a circular vacuum chamber of 1.2m in diameter and 25cm in height. A vacuum of 1mm Hg will be maintained inside the chamber. The targets will be placed one at a time at the center of the chamber. A special mechanism will be provided such that the changing of targets will not destroy the vacuum.

The emulsion stacks are of the K5 type and 3 cm x 5 cm x 600 μ in size. It will make an angle of 8^o with the recoil protons which emit from the target at about 88^o. The distance between the emulsions and the target is 1 meter.

The electronic detectors D1 and D2 are made of 700μ silicon semiconductor and NaI scintillator respectively. The detector D1 measures the energy loss ΔE and D2 determines E. Both detectors are connected to a coincidence circuit and a data converter system as shown in Figure 5. This apparatus has been used successfully in Experiment SC33 at CERN.

(4) Processing of Emulsion Stacks

Based on the cooperation terms among the collaborators, P. S. Young at Mississippi State University will take charge of the processing. In order to minimize both background and fading, we intend to carry out the processing soon after the exposure.

(5) Scanning and Data Analysis

The scanning of emulsion stacks and extraction of data from the emulsions and electronic detectors will be shared among the groups in Clermont-Ferrand, France; Mississippi, U.S.A.; and Valencia, Spain. Preliminary results should be reported within six months.

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FIGURE CAPTIONS

Figure 1: $\frac{dN}{dE}$ as function of recoil proton energy measured in an emulsion stack from the (p,p) experiment at CERN with E_p = 27 GeV

Figure 2: Charge and energy spectrum of the light fragments from (Exp. SC33)

Figure 3(a) and 3(b): $\frac{d^2N}{dEd\Omega}$ of light fragments from (p,C) collisions from (Exp. SC33)

Figure 4: Diagram of experimental setup

C: Target

E and ΔE: NaI and Silicon Detectors

C.E.: Emission Chamber

Figure 5: Block diagram of the coincidence circuit and the data digital converter system

FIG 1

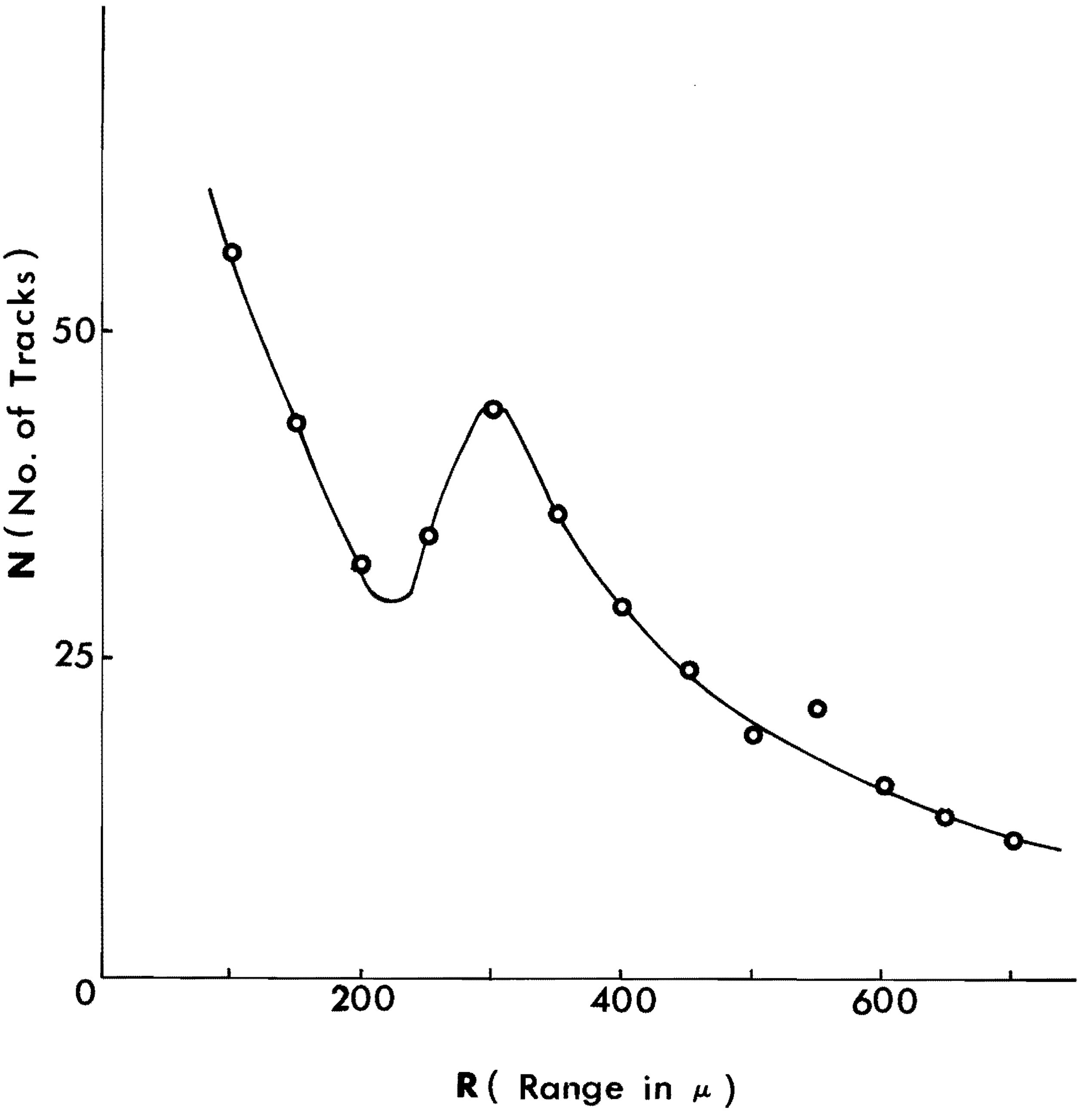
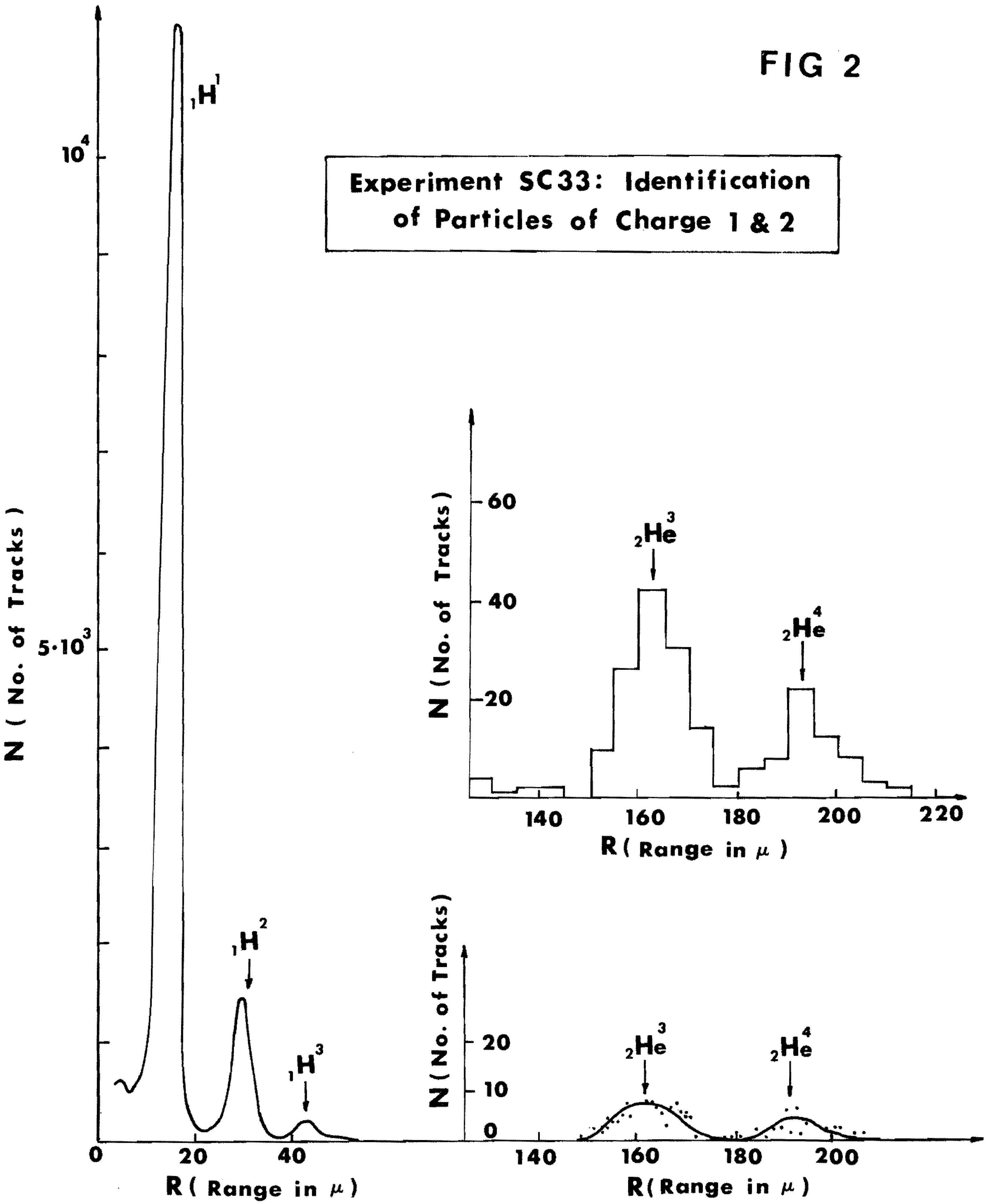


FIG 2


Experiment SC33: Identification of Particles of Charge 1 & 2
$_1H^1$
10^4
$5 \cdot 10^3$
N (No. of Tracks)
$_1H^2$
$_1H^3$
0
20
40
R (Range in μ)
N (No. of Tracks)
60
40
20
$_2He^3$
$_2He^4$
140
160
180
200
220
R (Range in μ)
N (No. of Tracks)
20
10
0
$_2He^3$
$_2He^4$
140
160
180
200
R (Range in μ)

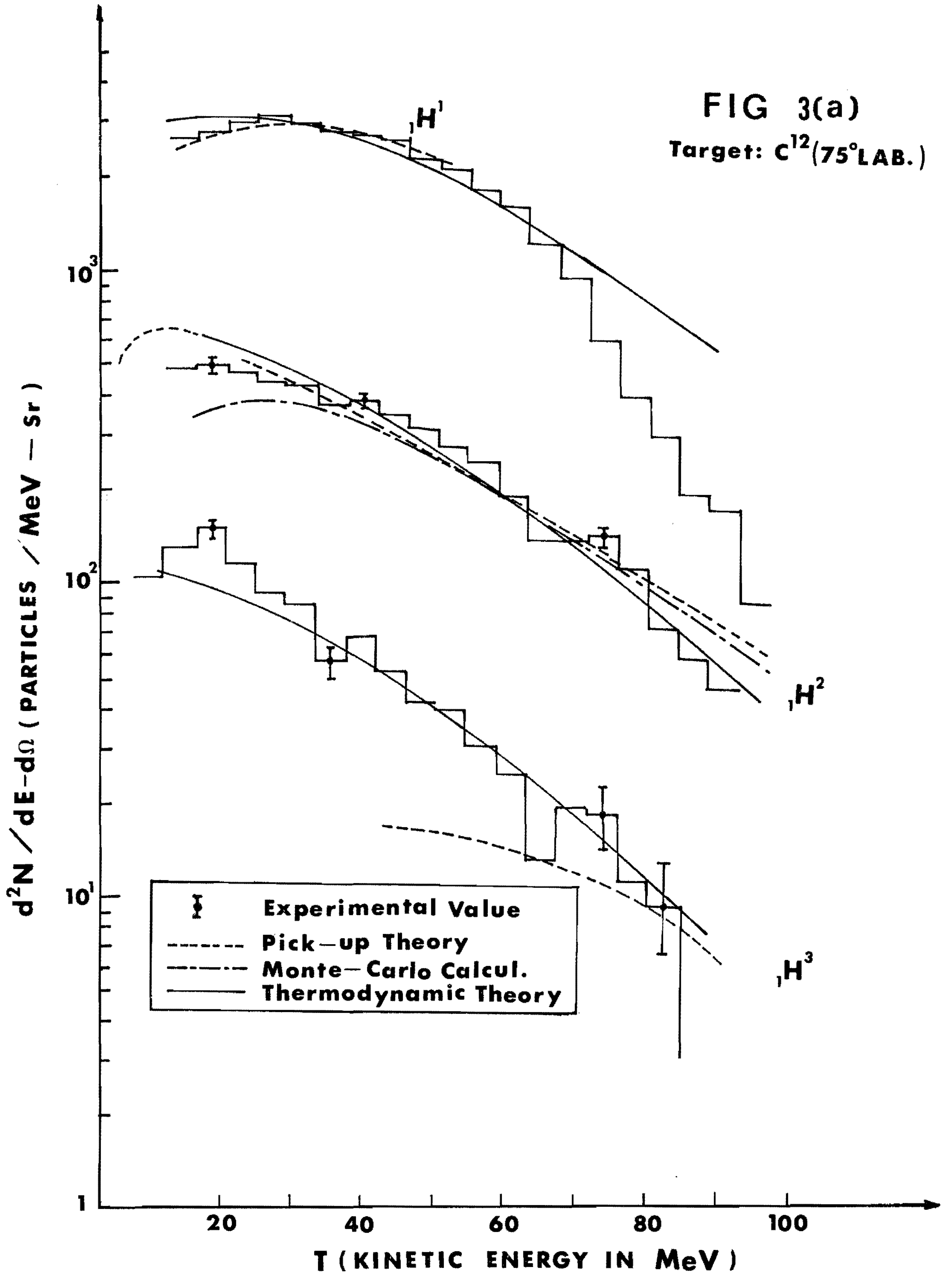


FIG 3(a)
Target: C^{12}(75°LAB.)
$_1H^1$
$_1H^2$
$_1H^3$
10^3
10^2
10^1
1
$d^2N / dE\text{-}d\Omega$ (PARTICLES / MeV — Sr)
20
40
60
80
100
T (KINETIC ENERGY IN MeV)
Experimental Value
Pick—up Theory
Monte—Carlo Calcul.
Thermodynamic Theory

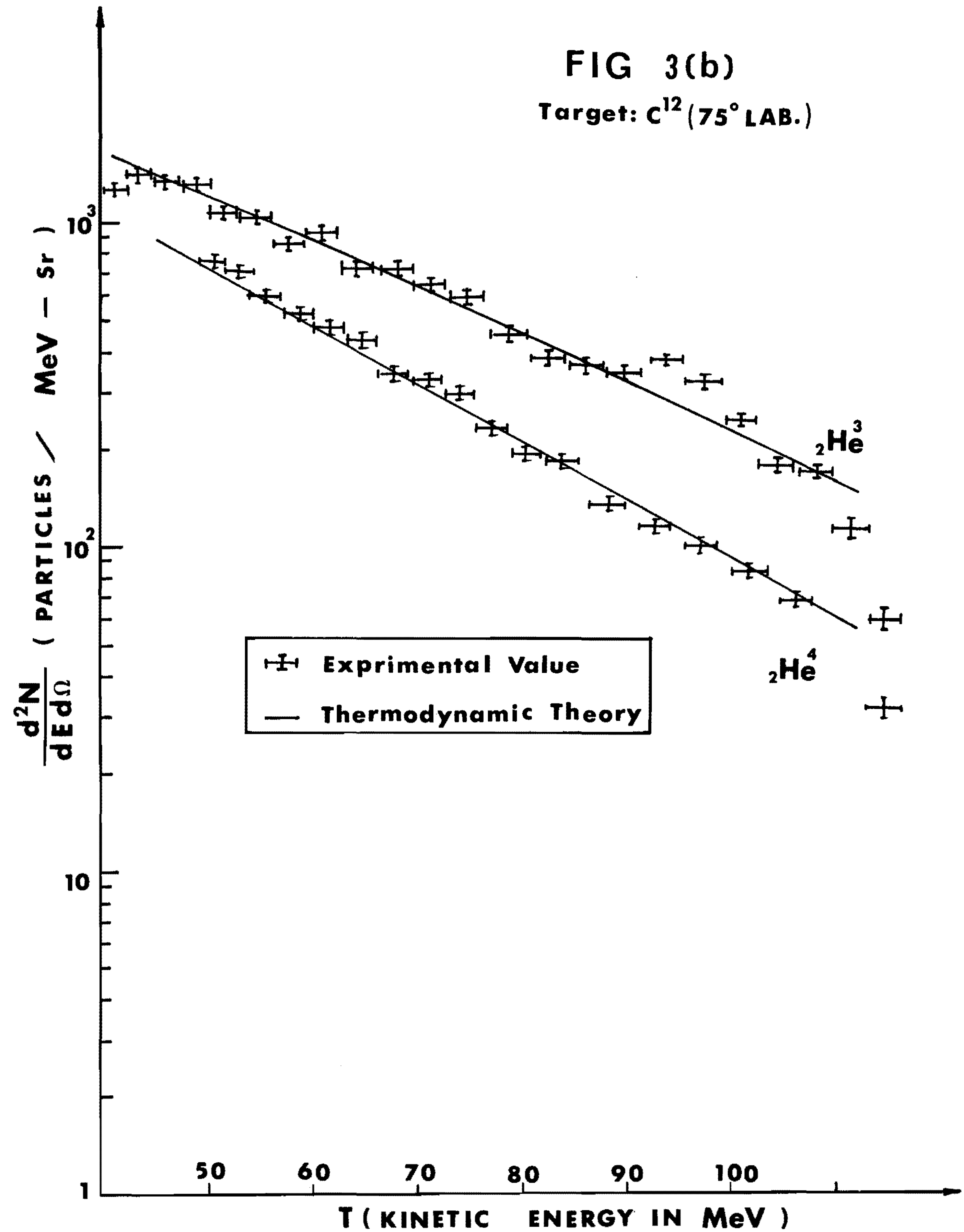


FIG 3(b)
Target: C12 (75° LAB.)
$_2He^3$
$_2He^4$
Exprimental Value
Thermodynamic Theory
$\frac{d^2N}{dE\,d\Omega}$ (PARTICLES / MeV − Sr)
10³
10²
10
1
50
60
70
80
90
100
T (KINETIC ENERGY IN MeV)

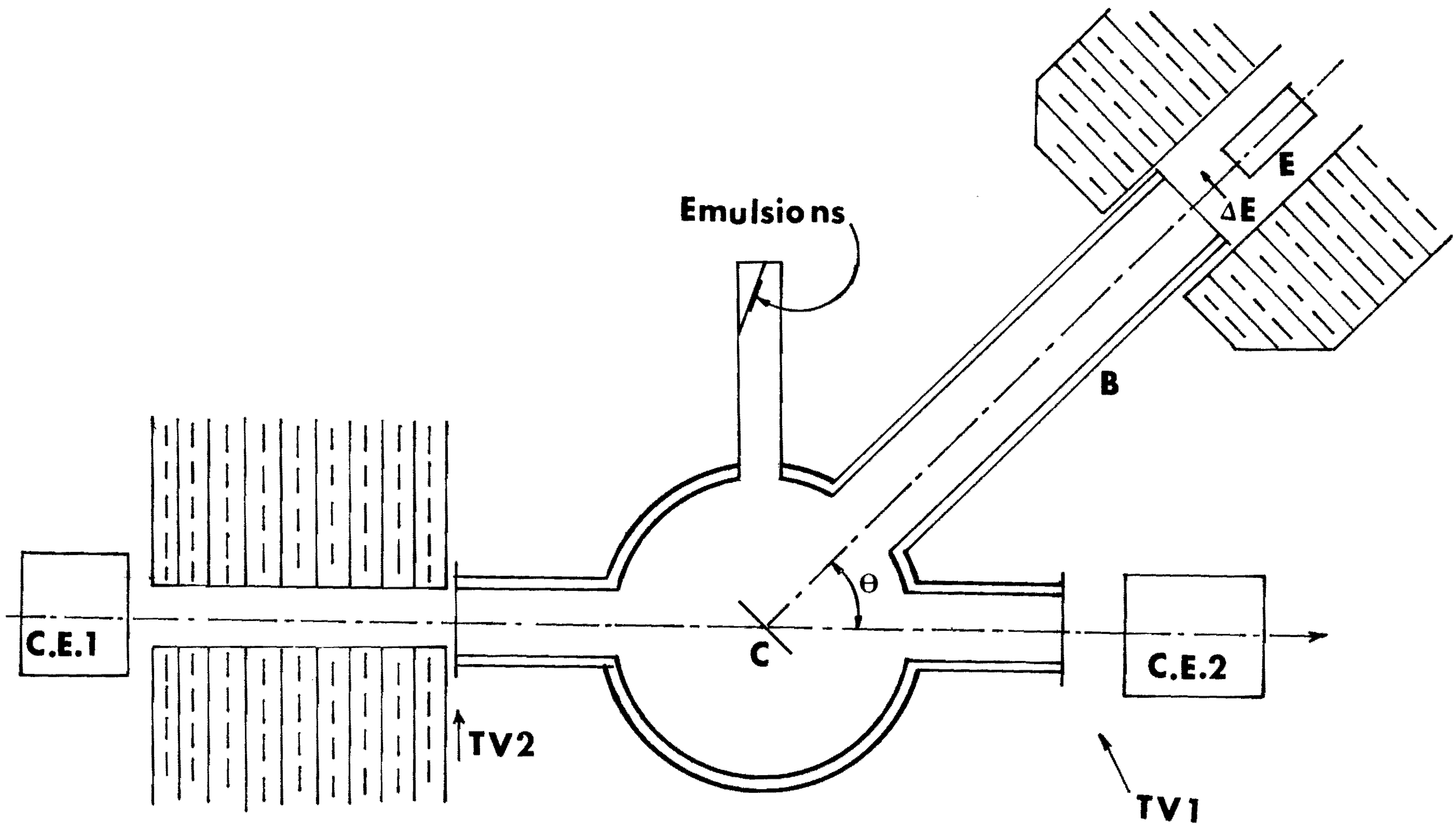


FIG 4

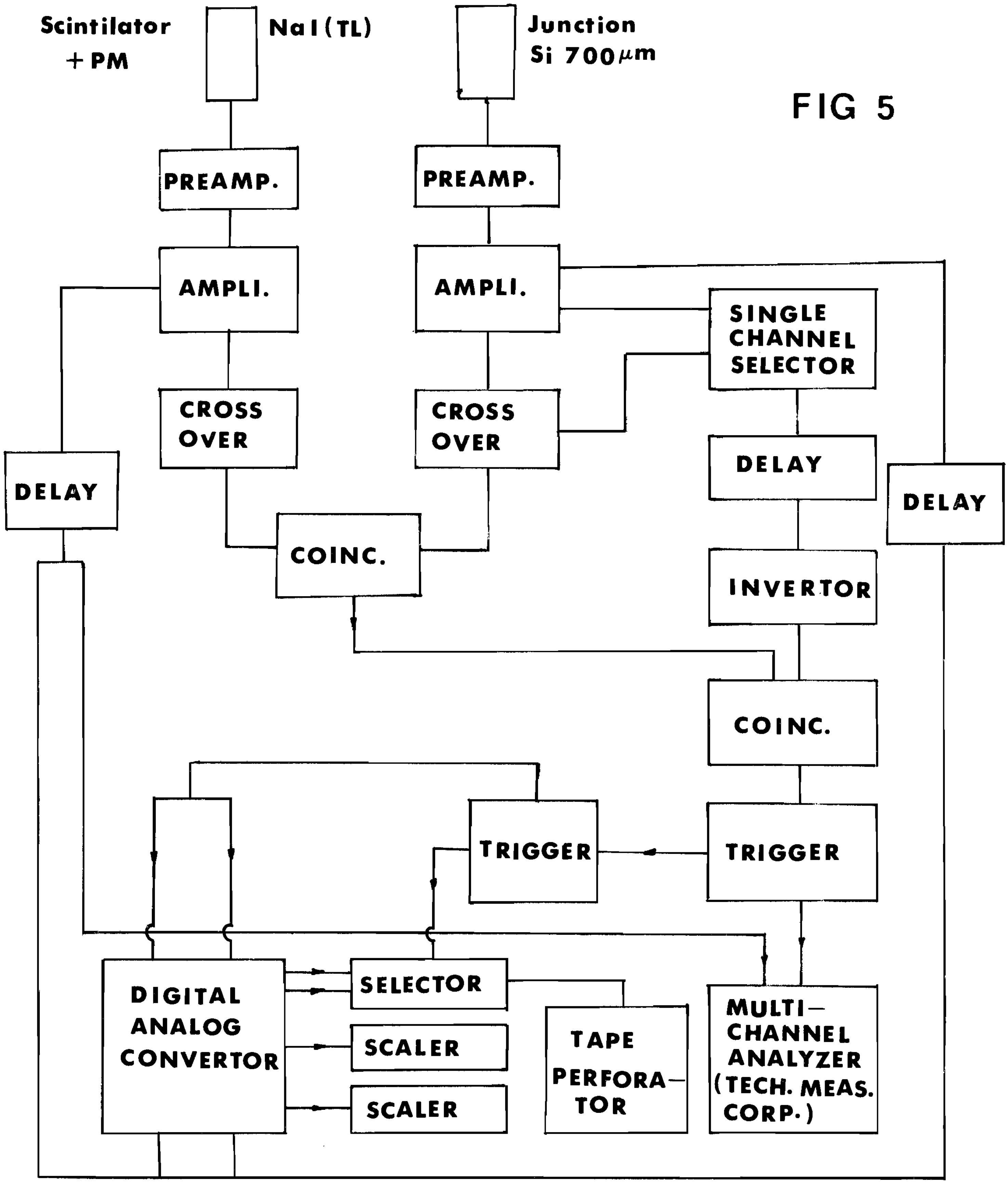

Scintilator
+ PM
Na I (TL)
Junction
Si 700μm
PREAMP.
PREAMP.
AMPLI.
AMPLI.
SINGLE CHANNEL SELECTOR
CROSS OVER
CROSS OVER
DELAY
DELAY
DELAY
COINC.
INVERTOR
COINC.
TRIGGER
TRIGGER
DIGITAL ANALOG CONVERTOR
SELECTOR
SCALER
SCALER
TAPE PERFORA-TOR
MULTI-CHANNEL ANALYZER (TECH. MEAS. CORP.)

FIG 5